APPLICATION

FOR

UNITED STATES PATENT APPLICATION

Entitled

ANTENNA CONFIGURATIONS FOR REDUCED RADAR COMPLEXITY

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CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a Continuation-in-Part of and claims the benefit of U.S. Patent Application No. 10/376,179 filed February 27, 2003, which is a Continuation-in-Part of and claims the benefit of U.S. Patent Application No. 10/293,880, filed November 13, 2002, which is a Continuation-in-Part of and claims the benefit of U.S. Patent Application No. 09/932,574, filed on August 16, 2001, which are each hereby incorporated by reference.

STATEMENTS REGARDING FEDERALLY SPONSORED RESEARCH

Not applicable.

FIELD OF THE INVENTION

This invention relates to a transmit/receive system and more particularly to a transmit/receive system which utilizes an array antenna having asymmetric transmit and receive antennas.

BACKGROUND OF THE INVENTION

As is known in the art, there is an increasing trend to include radar systems in commercially available products. For example, it is desirable to include radar systems in automobiles, trucks boats, airplanes and other vehicle. Such radar systems must be compact and relatively low cost.

Furthermore, some applications have relatively difficult design parameters including restrictions on the physical size of the structure, as well as minimum operational performance requirements. Such competing design requirements make the design of such radar systems relatively challenging. Among the design challenges is the challenge to provide an antenna system which meets the design goals of being low cost, compact and have relatively high performance.

In automotive radar systems, for example, cost and size considerations are of considerable importance. Furthermore, in order to meet the performance

requirements of automotive radar applications, (e.g. coverage area) an array antenna is required.

It would, therefore, be desirable to provide an antenna array that is compact which can operate in a high density circuit environment, and is relatively low cost to manufacture and yet provides an antenna array having relatively high performance characteristics.

SUMMARY OF THE INVENTION

In accordance with principles of the present invention, set forth is a transmit and receive system that is relatively compact and can operate in a high density circuit environment, and which is relatively low cost to manufacture and yet provides an antenna array having relatively high performance characteristics.

The transmit and receive system includes a first array including a first plurality of antenna element disposed to provide a transmit antenna. A beam switching system is coupled to the first array and is operative to form a plurality of transmit beams.

The transmit and receive system further includes a second array including a second plurality of antenna elements disposed to provide a receive antenna. A beam combining system is coupled to the second array and is operative to form a plurality of receive beams. In accordance with aspects of the present invention, predetermined ones of the plurality of transmit beams and predetermined ones of the plurality of receive beams are combined to form a plurality of two-way beams.

In another aspect of the present invention, a method of forming a plurality of two-way radiation beams using a transmit and receive system is set forth. The method includes controlling a transmit antenna array of the transmit and receive system to provide a plurality of transmit radiation beams. A receive antenna array of the transmit and receive system is also controlled to sense a plurality of receive radiation beams. Further, predetermined ones of the plurality of transmit beams and predetermined ones of the plurality of receive beams are combined to form the plurality of two-way radiation beams.

In an aspect, controlling the transmit antenna array includes controlling a beam switching system, which is coupled to the transmit antenna array, to provide the plurality of transmit radiation beams. In addition, controlling the receive antenna array includes controlling a beam combining system, which is coupled to the receive antenna array, to provide the plurality of receive radiation beams.

In accordance with one particular aspect of the present invention, predetermined ones of the plurality of transmit beams and predetermined ones of the

plurality of receive beams are combined to form ten two-way radiation beams. More particularly, a first transmit radiation beam of the plurality of transmit radiation beams is combined with a first receive radiation beam of the plurality of receive radiation beams to provide a first two-way radiation beam. The first transmit radiation beam of the plurality of transmit radiation beams is combined with a second receive radiation beam of the plurality of receive radiation beams to provide a second two-way radiation beam.

Further, a second transmit radiation beam of the plurality of transmit radiation beams is combined with the second receive radiation beam of the plurality of receive radiation beams to provide a third two-way radiation beam. The second transmit radiation beam of the plurality of transmit radiation beams is combined with a third receive radiation beam of the plurality of receive radiation beams to provide a fourth two-way radiation beam. The second transmit radiation beam of the plurality of transmit radiation beams is combined with a fourth receive radiation beam of the plurality of receive radiation beams to provide a fifth two-way radiation beam.

Yet further, a third transmit radiation beam of the plurality of transmit radiation beams is combined with the fourth receive radiation beam of the plurality of receive radiation beams to provide a sixth two-way radiation beam. The third transmit radiation beam of the plurality of transmit radiation beams is combined with a fifth receive radiation beam of the plurality of receive radiation beams to provide a seventh two-way radiation beam. The third transmit radiation beam of the plurality of transmit radiation beams is combined with a sixth receive radiation beam of the plurality of receive radiation beams to provide an eighth two-way radiation beam.

A fourth transmit radiation beam of the plurality of transmit radiation beams is combined with the sixth receive radiation beam of the plurality of receive radiation beams to provide a ninth two-way radiation beam. Finally, the fourth transmit radiation beam of the plurality of transmit radiation beams is combined with a seventh receive radiation beam of the plurality of receive radiation beams to provide a tenth two-way radiation beam.

In accordance with another aspect of the present invention, predetermined

ones of the plurality of transmit beams and predetermined ones of the plurality of receive beams are combined to form seven two-way radiation beams. More particularly, a first transmit radiation beam of the plurality of transmit radiation beams is combined with a first receive radiation beam of the plurality of receive radiation beams to provide a first two-way radiation beam. A second transmit radiation beam of the plurality of transmit radiation beams is combined with the first receive radiation beam of the plurality of receive radiation beams to provide a second two-way radiation beam. The second transmit radiation beam of the plurality of transmit radiation beams is combined with a second receive radiation beam of the plurality of receive radiation beams to provide a third two-way radiation beam.

Further, a third transmit radiation beam of the plurality of transmit radiation beams is combined with the second receive radiation beam of the plurality of receive radiation beams to provide a fourth two-way radiation beam. The third transmit radiation beam of the plurality of transmit radiation beams is combined with a third receive radiation beam of the plurality of receive radiation beams to provide a fifth two-way radiation beam. A fourth transmit radiation beam of the plurality of transmit radiation beams is combined with the third receive radiation beam of the plurality of receive radiation beams to provide a sixth two-way radiation beam. Finally, the fourth transmit radiation beam of the plurality of transmit radiation beams is combined with a fourth receive radiation beam of the plurality of receive radiation beams to provide a seventh two-way radiation beam.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing features of this invention, as well as the invention itself, may be more fully understood from the following description of the drawings in which:

Fig. 1 is a top plan view of an asymmetric antenna array in accordance with an embodiment of the present invention;

Fig. 2 is a block diagram of a beam switching system adapted for coupling to the asymmetric antenna array, as shown in Fig. 1;

Fig. 3 is a block diagram of beam combining system adapted for coupling to the asymmetric antenna array, as shown in Fig. 1;

Fig. 4 is an illustration of a plurality of beams generated by a Butler Matrix circuit of the beam combining system of Fig. 3;

Fig. 4A is an illustration of an overlay of a plurality of receive beams generated by the beam combining system of Fig. 3 and a plurality of transmit beams generated by the beam switching system of Fig. 2;

Fig. 5 is a graph illustrating radiation patterns associated with the plurality of receive beams generated by the beam combining system of Fig. 3;

Fig. 6 is a top plan view of an asymmetric antenna array in accordance with another embodiment of the present invention;

Fig. 7 is a block diagram of beam switching system and/or beam combining system adapted for coupling to the asymmetric antenna array, as shown in Fig. 6;

Fig. 7B is a block diagram of another embodiment of the beam switching system and/or beam combining system adapted for coupling to the asymmetric antenna array, as shown in Fig. 6;

Fig. 8 is an illustration of an overlay of a plurality of receive beams and a plurality of transmit beams generated by the beam switching system and/or beam combining system of Fig. 7;

Fig. 9 is a graph illustrating radiation patterns associated with the plurality of receive beams generated by the beam switching system and/or beam combining system of Fig. 7;

Fig. 10 is a top plan view of an asymmetric antenna array in accordance with another embodiment of the present invention;

Fig. 11 is a block diagram of beam switching system adapted for coupling to the asymmetric antenna array, as shown in Fig. 10;

Fig. 12 is a graph illustrating radiation patterns associated with the plurality of receive beams generated by the beam combining system of Fig. 3, which is adapted for coupling to the asymmetric antenna array, as shown in Fig. 10;

Fig. 13 is an illustration of an overlay of a plurality of receive beams and a plurality of transmit beams respectively generated by the beam switching system and beam combining system of Figs. 2 and 3; and

Fig. 14 is a graph illustrating radiation patterns representing a predetermined combination of the plurality of receive beams and the plurality of transmit beams as provided by the beam combining system of Fig. 3.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig. 1, set forth is an asymmetric antenna array 10 provided from a substrate 11 having a length L and width W. The asymmetric antenna array 10 includes a first plurality of antenna elements disposed on the substrate 11 to provide a transmit antenna array 12 and a second plurality of antenna elements disposed on the substrate 11 to provide a receive antenna array 14. In one embodiment, the transmit antenna array 12 includes four rows 16a – 16d and three columns 18a – 18c and the receive antenna array 14 includes eight rows 20a – 20h and six columns 22a – 22f. Thus, the transmit antenna array 12 includes twelve radiating elements (or more simply "radiators" or "elements"), generally denoted 24, with four elements in azimuth and three elements in elevation. Additionally, the receive antenna array 14 includes forty-eight radiating elements (or more simply "radiators" or "elements"), generally denoted 26, with eight elements in azimuth and six elements in elevation.

It should be understood that a number of permutations of arrangements and quantities of radiators 24 can be disposed on the substrate 11 to define the transmit array 12 as long as the quantity of radiators 24 differs from the quantity of radiators 26 disposed on the substrate 11 to define the receive array 14. Similarly, it should be understood that a number of permutations of arrangements and quantities of radiators 26 can be disposed on the substrate 11 to define the receive array 14 as long as the quantity of radiators 26 differs from the quantity of radiators 24 disposed on the substrate 11 to define the transmit array 12. As will be described below in conjunction with Figs. 2-5, the transmit array 12 is coupled to a transmit signal path and the receive array 14 is coupled to a receive signal path.

Referring to Fig. 2, in the exemplary embodiment, a beam switching system 40 includes a beamformer circuit 41 which in this particular embodiment is shown as a Butler matrix beam forming network 41 having a plurality of antenna element ports 42a-42d generally denoted 42 and a plurality of switch ports 44a – 44d. In an embodiment, the antenna element port 42 can be coupled to a transmit antenna array, such as the transmit antenna array 12 of Fig. 1, which is described in detail below.

The transmission lines 45a – 45d respectively couple each of the switch ports 44a – 44d of the beamformer circuit 41 to a switched beam combining circuit 46.

Optionally, one, some or all of the transmission lines 45a-45d can include amplitude control elements 43a –43d which may be provided, for example, as an attenuator or as an amplifier. The amplitude control elements 43a –43d may be used for example, to control the signal levels in individual beams emitted from each of the corresponding antenna element ports 42a-42d, as described above. Although not shown in the figures, similar amplitude control elements can also be coupled between the beamformer circuit 41 and some or all of the antenna element ports 42a-42d, which provides additional control to the signal levels in individual beams emitted from each of the antenna element ports 42a-42d.

In the exemplary embodiment, the signal path between beamformer port 44a and switch port 47a includes an amplitude control element, as does the signal path between beamformer port 44d and switch port 47d. In this arrangement, the signal levels in individual beams emitted from each of the antenna element ports 42a-42d will be substantially equivalent. In other words, the signal levels in individual beams emitted from each of the antenna element ports 42a-42d will include substantially equivalent radiant energy.

The switched beam combining circuit 46 is here provided from a single pole four throw switch 46 having a common port 49 coupled to the output port of the beam switching system 40. The common port 49 is coupled to a signal generator 50.

In one embodiment, each of the antenna element ports 42a-42d are coupled to corresponding ones of the four rows 16a – 16d of the transmit antenna array 12, shown in Fig. 1. It should be understood that the plurality of antenna element ports 42a-42d of the antenna port 42 is scalable. Thus, in the event that an array antenna having more than four rows was used, it would be possible to make appropriate changes to the beamformer circuit to provide the beamformer circuit having an appropriate number of antenna ports 42.

Referring now to Fig. 3, a beam combining system 80 includes a beamforming circuit 60 having a plurality of antenna element ports 62a - 62h generally denoted 62 and a plurality of switch ports 64a – 64h generally denoted 64. In this exemplary embodiment, the beamforming circuit 60 is shown as a Butler matrix beamforming

network. In an embodiment, the antenna element port 62 can be coupled to a receive antenna array, such as the receive antenna arrant 14 of Fig. 1, which is described in detail below.

The switch ports 64 are coupled through transmission lines 66a –66h to a switched beam combining circuit 70. As is known, the port phasing for a Butler matrix have 180° phase difference and the curved signal paths 66a, 66c, 66f, 66h represent 180° differential line lengths required to bring all of the ports in phase with each other. The switched beam combining circuit 70 is here provided from a pair of single pole four throw switches 74, 75. Each of the switches 74, 75 include a common port 71, 73 coupled to respective output ports 76, 78 of a power divider circuit 77. The power divider circuit 77 is provided such that a signal fed to an input port 79 has an equal phase and power level at the output ports 76, 78. In this example, the port 79 is coupled to a receiver circuit 82, via an output port 81.

In one embodiment, the plurality of antenna element ports 62a-62h are coupled to corresponding ones of the rows 20a – 20h of the receive antenna array 14, shown in Fig. 1. It should be understood that the plurality of antenna element ports 62a-62h of the antenna port 62 is scalable to accommodate a plurality of different receive antenna arrays (not shown) having a plurality of rows of radiators or elements.

Referring to Fig. 4, in this particular embodiment, the Butler beamforming circuit 60 (Fig. 3) forms eight beams 120a – 120h. That is, by providing an input signal to one of the plurality of antenna ports 62 of the Butler matrix 60, which input signal is provided from the receive antenna 26, the Butler matrix 60 generates a corresponding one of the beams 120a – 120h at a corresponding one of the plurality of switch ports 64 thereof. The calculations for determining the beam locations can be found using the equations below:

Wavelength (inches): $\lambda := \frac{11.81}{24}$

Number of Elements: $N := 8$

Element Spacing (Azimuth): $d := .223$

Beam Location (Degrees): $\mathrm{beamloc}(M) := \mathrm{asin}\left[\frac{\lambda}{N \cdot d} \cdot \left(M - \frac{1}{2}\right)\right] \cdot \frac{180}{\pi}$

Beam Number: $M := 1 .. \frac{N}{2}$

If the array is provided having an array lattice spacing of 0.223" in azimuth, the beam locations shown in Fig. 4 are provided. In one embodiment, the differential line length value, n is selected to be 1/16 λ which corresponds to 0.0127 inch at a frequency of 24 GHz. Fig. 7 also illustrates which beam-ports in Fig. 6 produce which beams.

Referring now to Fig. 4A, a calculated antenna radiation pattern 122 includes four transmit beams 123a-123d and seven receive beams 124a – 124g which can be used in a radar system. The four transmit beams are formed by feeding a transmit signal produced by signal source 50 (Fig. 2) through the switch 46. Depending upon the switch path which is selected, a signal is provided to one of the Butler matrix ports 44a – 44d (Fig. 2). The Butler beamforming circuit 40 then forms one of the four transmit antenna beams 123a – 123d. That is, by providing an input signal to one of the Butler matrix input ports 44a – 44d (Fig. 2), the transmit antenna 12 (Fig. 1) produces a corresponding one of the beams 123a – 123d.

The seven receive beams 124a – 124g are provided by combining predetermined ones of the eight beams 120a – 120h (Fig. 4) formed by the Butler Matrix 60 (Fig. 3) as discussed above. Adjacent beams (e.g. beams 120a, 120b from Fig. 4) can be combined to produce beam 124a as illustrated in Figure 4A. Since beams out of a Butler Matrix by definition are orthogonal, combining beams in azimuth produces a cos(θ) taper with a peak sidelobe level of 23 dB (with respect to the beam maximum).

The locations of the combined received beams are listed in the Table below.

TABLE

Combined Beam	Beam Location
8,1	0
4,8 & 1,5	+/- 16

6,4 & 5,3	+/- 34
2,6 & 3,7	+/- 57

In elevation, there is also a 25 dB Chebyshev taper and a 15° beam steer.

Referring to Fig. 5, a two-way radiation pattern having seven antenna beams 130a – 130g is produced by an array antenna having an array of antenna elements provided as described above in conjunction with Fig. 1 and having the transmit array 12 coupled to a transmit path of the type described above in conjunction with Fig. 2 and having the receive array 14 coupled to a receive path of the type described above in conjunction with Fig. 3.

Referring to Fig. 6, set forth is another embodiment of an asymmetric antenna array 210 in accordance with the present invention. The asymmetric antenna array 210 can be disposed on a substrate 211 having a length L and width W. The asymmetric antenna array 210 includes a first plurality of antenna elements disposed on the substrate 211 to provide a transmit antenna array 212 and a second plurality of antenna elements disposed on the substrate 211 to provide a receive antenna array 214. In one embodiment, the transmit antenna array 212 includes four rows 216a – 216d and three columns 218a – 218c and the receive antenna array 214 includes four rows 220a –220d and six columns 222a – 222f. Thus, the transmit antenna array 212 includes twelve radiating elements (or more simply "radiators" or "elements"), generally denoted 224, with four elements in azimuth and three elements in elevation. Additionally, the receive antenna array 214 includes twenty-four radiating elements (or more simply "radiators" or "elements"), generally denoted 226, with four elements in azimuth and six elements in elevation.

It should be understood that a number of permutations of arrangements and quantities of radiators 224 can be disposed on the substrate 211 to define the transmit array 212 as long as the quantity of radiators 224 differs from the quantity of radiators 226 disposed on the substrate 211 to define the receive array 214. Similarly, it should be understood that a number of permutations of arrangements and quantities of radiators 226 can be disposed on the substrate 211 to define the receive array 214 as

long as the quantity of radiators 226 differs from the quantity of radiators 224 disposed on the substrate 211 to define the transmit array 212.

Referring to Fig. 7, in the exemplary embodiment, a beam switching system 240 includes a beamformer circuit 241, which in this particular embodiment is shown as a Butler matrix beam forming network 241 having a plurality of antenna element ports 242a-242d generally denoted 242 and a plurality of switch ports 244a – 244d. In one embodiment, the antenna element port 242 can be coupled to a transmit antenna array, such as the transmit antenna array 212 of Fig. 6 (e.g. beam switching system 240 is employed to transmit signals to the transmit antenna array 212, via the antenna element port 242), which is described in detail below. In another embodiment, the antenna element port 242 can be coupled to a receive antenna array, such as the receive antenna array 214 of Fig. 6 (e.g. beam switching system 240 is employed to receive signals from the receive antenna array 214, via the antenna element port 242), which is also described in detail below.

The transmission lines 245a – 245d couple each of the switch ports 244a – 244d to a switched beam combining circuit 246. Optionally, one, some or all of the transmission lines 245a-245d can include an amplitude control element, which is similar to that shown and described above in connection with Fig. 2. In the exemplary embodiment, the signal path between beamformer port 244a and switch port 247a includes an amplitude control element as does the signal path between beamformer port 244d and switch port 247d.

The switched beam combining circuit 246 is here provided from a single pole four throw switch 246 having a common port 249 coupled to the output port of the beam switching system 240. The common port 249 can be coupled to a signal generator 250 when the beam switching system 240 is employed to transmit a plurality of signal to the transmit antenna 224 (Fig. 6), via the antenna port 242. In an embodiment, each of the antenna element ports 242a-242d are coupled to corresponding ones of the four rows 216a – 216d of the transmit antenna array 212, as shown in Fig. 6. It should be understood that the plurality of antenna element ports 242a-242d of the antenna port 242 is scalable. Thus, in the event that a transmit array antenna 212 having more than four rows was used, it would be possible to make

appropriate changes to the beamformer circuit 241 of the beam switching system 240 to provide the beamformer circuit 241 having an appropriate number of antenna ports 242.

In addition, it should be understood that a beam combining system (not shown) can be similarly constructed and arranged as the beam switching system 240. Therefore, for illustrative purposes, the beam switching system 240 can be redefined as the beam combining system 240, where like components are referred to using like reference designations. The beam combing system 240 includes a signal receiver circuit 252 coupled to the common output port 249 of the switch 246. In an embodiment, each of the antenna element ports 242a-242d are coupled to corresponding ones of the four rows 220a – 220d of the receive antenna array 214, shown in Fig. 6. It should be understood that the plurality of antenna element ports 242a-242d of the antenna port 242 is scalable. Thus, in the event that a receive array antenna 214 having more than four rows was used, it would be possible to make appropriate changes to the beamformer circuit 241 of the beam combining circuit 240 to provide the beamformer circuit 241 having an appropriate number of antenna ports 242.

Referring to Fig. 7B, shown is another exemplary embodiment of a beam switching system and/or beam combining system 240′, which is similarly constructed and arranged as the beam switching system and/or beam combining system 240, as shown and described above with respect to Fig. 7, where like components are referred to using like reference designations. In Fig. 7B, the beam switching system and/or beam combining system 240′ further includes a number of phase shifters 243a, 243b, 243c and 243d, which are coupled between each of the respective antenna element ports 242a, 242b, 242c and 242d and the beamformer circuit 241.

During transmission of signals from the signal generator 250 through the beam switching system and/or beam combining system 240′ to the transmit antenna array 212 (Fig. 6), via the antenna element ports 242a, 242b, 242c and 242d, each of the corresponding phase shifters 243a, 243b, 243c and 243d introduce a predetermined phase shift to the transmitted signal, which introduces a corresponding phase shift or

"squint" to the antenna beam signal emitted from the transmit antenna array 212. In one embodiment, the phase shifters 243a, 243b, 243c and 243d can be constructed and arranged to introduce a phase shift or squint to the antenna beam emitted from the transmit antenna array 212 of approximately one-half a beam width in a first predetermined direction (e.g. to the left).

Similarly, when the antenna receives a signal (e.g. receive antenna array 214 on Fig. 6 receives a signal), the signal is fed to ports 242a-242d and subsequently propagates through phase shifters 243a, 243b, 243c and 243d. The phase shifters 243a-243d introduce a predetermined phase shift to the received signal, which introduces a corresponding shift or squint to the positions of the receive antenna beams produced by the receive antenna array. In one embodiment, the phase shifters 243a, 243b, 243c and 243d can be constructed and arranged to introduce a shift or squint to the antenna beam signal received from the receive antenna array 214 of approximately one-half a beam width in a second predetermined direction (e.g. to the right).

Referring to Fig. 8, shown is an overlay 322 (illustration does not depict actual beam shapes and locations) and combination of transmit beams 323a-323d and receive beams 324a-324d, which operate to form the seven two-way beams 325a-325g, as described herein. In the exemplary embodiment, the transmit beams 323a-323d and receive beams 324a-324d are squinted or phase-shifted approximately one-half a beam width in opposite direction with respect to each other. Furthermore, adjacent transmit beams 323a-323d and receive beams 324a-324d can be combined to form the seven two-way beams 325a-325g.

In an embodiment, the transmit beam 323a can be combined with receive beam 324a to form two-way beam 325a. Further, the transmit beam 323b can be combined with receive beam 324a to form two-way beam 325b. The transmit beam 323b can be combined with receive beam 324b to form two-way beam 325c. The transmit beam 323c can be combined with receive beam 324b to form two-way beam 325d. The transmit beam 323c can be combined with receive beam 324c to form two-way beam 325e. The transmit beam 323d can be combined with receive beam 324c to

form two-way beam 325f. Finally, the transmit beam 323d can be combined with receive beam 324d to form two-way beam 325g.

Referring to Fig. 9, a two-way radiation pattern having seven antenna beams 330a – 330g is produced by an array antenna having an array of antenna elements provided as described above in conjunction with Fig. 6 and having the transmit antenna array 212 and the receive antenna array 214 coupled to a transmit and/or receive path of the type described above in conjunction with Fig. 7. Fig. 9 shows a typical two-way antenna radiation pattern 330 corresponding to the seven two-way beams 325a-325g, as shown in Fig. 8. The number of beams and beam coverage are substantially the same as that shown and described above with respect to Fig. 5. The side-lobe levels associated with each of the seven two-way beams 330a-330g are approximately below the 40dB level. Further, it should be recognized that any loss in transmit gain or receive sensitivity is relatively insignificant and does not necessitate amplification using additional amplifiers. In addition, it should also be recognized that even though the seven two-way beams 330a-330g include slightly broader beamwidths than the seven two-way beams 130a-130g of Fig. 5, which affects the degree to which the detection coverage zone can be shaped, the seven two-way beams 330a-330g remain particularly useful in radar system applications.

Referring to Fig. 10, set forth is another embodiment of an asymmetric antenna array 410 in accordance with the present invention. The asymmetric antenna array 410 can be disposed on a substrate 411 having a length L and width W. The asymmetric antenna array 410 includes a first plurality of antenna elements disposed on the substrate 411 to provide a transmit antenna array 412 and a second plurality of antenna elements disposed on the substrate 411 to provide a receive antenna array 414. In one embodiment, the transmit antenna array 412 includes one row 416 and three columns 418a – 418c and the receive antenna array 414 includes eight rows 420a –420h and six columns 422a – 422f. Although the respective row(s) and columns of the transmit antenna array 412 and the receive antenna array 414 have been respectively disclosed as being vertically oriented and horizontally oriented, it should be understood that these definitions can be modified to re-define the vertically oriented radiators as columns and the horizontally oriented radiators as rows.

In an embodiment, the transmit antenna array 412 includes three radiating elements (or more simply "radiators" or "elements"), generally denoted 424, with one element in azimuth and three elements in elevation. Additionally, the receive antenna array 414 includes forty-eight radiating elements, generally denoted 426, with eight elements in azimuth and six elements in elevation.

Although not specifically shown, it should be understood that the transmit antenna array 412 can include one row 416 and one column, such as column 418a. Thus, the transmit antenna array 412 can include a single radiating element (or more simply "radiator" or "element"), generally denoted 424, with one element in azimuth and one elements in elevation.

It should also be understood that a number of permutations of arrangements and quantities of radiators 424 can be disposed on the substrate 411 to define the transmit array 412 as long as the quantity of radiators 424 which define the transmit array differs from the quantity of radiators 426 which define the receive antenna array 414. Similarly, it should be understood that a number of permutations of arrangements and quantities of radiators 426 which define the receive array 414 as long as the quantity of radiators 426 differs from the quantity of radiators 424 which define the transmit array 412.

Referring to Fig. 11, in the exemplary embodiment, a beam switching system 440 includes a beamformer circuit 441, which in this particular embodiment is shown as a Butler matrix beam forming network 441 having at least one antenna element port 442a and at least one switch port 444. In the exemplary embodiment, the antenna port 442 is coupled to the row 416 of the transmit antenna array 412, as shown in Fig. 10. Further, the switch port 444 is coupled to an output 450a of a signal generator 450. It should be understood that the at least one antenna element 442a of the antenna port 442 is scalable. Thus, in the event that a transmit antenna array 412 having more than one row was used, it would be possible to make appropriate changes to the beamformer circuit 441 of the beam switching system 440 to provide the beamformer circuit 441 having an appropriate number of antenna ports 442.

Referring again to Fig. 3, the beam combining system 80 can be similarly

coupled to the receive antenna array 414 of Fig. 10 as that previously shown and described above for coupling the beam combining system 80 to the receive antenna 26 of Fig. 3. Thus, a plurality of signals received by the receive antenna array 414 of Fig. 10 can be realized at the receiver circuit 82, via the output 81, as shown in Fig. 3.

Referring to Fig. 12, a two-way radiation pattern having seven antenna beams 460a – 460g is produced by an array antenna having an array of antenna elements as described above in conjunction with Fig. 10. The side-lobe levels associated with each of the seven two-way beams 460a-460g are approximately below the 20dB level. In the exemplary embodiment, it should be understood that an increase in the transmit energy or power provided to the transmit antenna can increase the system performance. Thus, transmit energy or power provided to the transmit antenna can be controlled to accommodate a particular application for the asymmetric antenna array, while at the same time providing a cost efficient asymmetric antenna array.

Although not specifically shown, it should be understood that the asymmetric antenna arrays 10, 210 and 410 respectively shown in Figs. 1, 6 and 10, can each be substituted with a plurality of other types of antenna arrays having a plurality of other types of radiators arranged in a plurality of configurations without departing from the spirit and scope of the present invention.

In another embodiment of the present invention, the asymmetric antenna array 10, the beam switching system 40 and the beam combining system 80, as respectively shown and described above in detail with respect to Figs. 1-3, can be controlled to provide ten two-way beams 515a-515j, which will be described below in connection with Figs. 13 and 14.

Referring now to Fig. 13, shown is an overlay 500 (illustration does not depict actual beam shapes and locations) and combination of transmit beams 505a-505d and receive beams 510a-510g, which operate to form the ten two-way beams 515a-515j, as described herein. In the exemplary embodiment, adjacent transmit beams 505a-505d and receive beams 510a-510d can be combined to form the ten two-way beams 515a-515g.

In an embodiment, the transmit beam 505a can be combined with receive beam 510a to form a first two-way beam 515a. Further, the transmit beam 505a can be combined with receive beam 510b to form a second two-way beam 515b. The transmit beam 505b can be combined with receive beam 510b to form a third two-way beam 515c. The transmit beam 505b can be combined with receive beam 510c to form a fourth two-way beam 515d. The transmit beam 505b can be combined with receive beam 510d to form a fifth two-way beam 515e. The transmit beam 505c can be combined with the receive beam 510d to form a sixth two-way beam 515f. The transmit beam 505c can be combined with receive beam 510e to form a seventh two-way beam 515g. The transmit beam 505c can be combined with receive beam 510f to form an eighth two-way beam 515h. The transmit beam 505d can be combined with receive beam 510f to form a ninth two-way beam 515i. The transmit beam 505d can be combined with receive beam 510g to form a tenth two-way beam 515j.

Although not specifically described herein, it should be understood that in accordance with various embodiments of the present invention, there exists a plurality of permutations of combinations of transmit and receive beams that can be formed to provide a number of two-way beams having various attributes. For example, greater than ten two-way beams can be formed by combining the transmit and receive beams in other manners than specifically provided herein. Furthermore, fewer than ten two-way beams can be formed, such as seven two-way beams as described above in detail with respect to Fig. 8.

Referring to Fig. 14, a two-way radiation pattern 600 having ten antenna beams 600a – 600j is produced by the asymmetric antenna array 10 of Fig. 1, which includes the transmit antenna array 12 coupled to the beam switching system 40 of Fig. 2 and the receive antenna array 14 coupled to the beam combining system 80 of Fig. 3. In Fig. 14, the ten antenna beams 600a – 600j of the two-way antenna radiation pattern 600 correspond to the ten two-way beams 515a-515j, as shown in Fig. 13. The side-lobe levels associated with each of the ten antenna beams 600a – 600j of the two-way antenna radiation pattern 600 are approximately below the 27dB level. Furthermore, the ten antenna beams 600a – 600j of the two-way antenna radiation pattern 600 provides many appreciable advantages, such providing a

detection zone having a relatively higher beam resolution, which is more conducive to shaping.

Having described the preferred embodiments of the invention, it will now become apparent to one of ordinary skill in the art that other embodiments incorporating their concepts may be used. It is felt therefore that these embodiments should not be limited to disclosed embodiments but rather should be limited only by the spirit and scope of the appended claims.